Magnetic Microstructure of Thin Fe Films on Ge.

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Introduction

We investigated the ferromagnetic (FM) domain structure of a 8nm thin Fe film grown on a Ge substrate using the Photoemission Electron Microscope at the ALS. Semiconductor surfaces used as a substrate for magnetic thin films attracted increased interest over the last decade, because of their broad availability and technological relevance. Furthermore they are usually more easy to prepare than for example single crystalline metal surfaces. Our goal is to prepare FM films exhibiting a cubic anisotropy and a moderate FM domain size of the order of a micrometer. The cubic anisotropy would lead to so called 90° domains, FM domains with a perpendicular alignment of their spin directions. These films can then be used as a substrate for antiferromagnetic (AFM) films exchange coupled to the FM substrate. The size of the AFM domains can then be controlled by the size of the FM domains and due to their perpendicular alignment they can be distinguished in our microscope.

Experimental

A Ge substrate was cleaned in water to remove the water soluble surface oxide layer. After introducing the substrate into the ultra high vacuum system ($p < 10^{-9}$mbar the substrate was annealed at 900K for 15 mins to remove adsorbates. An 8nm thick Fe film was then deposited by electron beam evaporation. We imaged the ferromagnetic domain structure employing the X-ray magnetic circular dichroism (XMCD). The XMCD effect of the FM 3d-metals is manifested in a change of intensity ratio at the L_3/L_2 edge. For a given element the ratio is proportional to the degree of circular polarization and the cosine of the angle between spin and helicity. A FM domain map is obtained by acquiring images at each absorption resonance and dividing them by each other. The resulting image is a map of the angle between spin and helicity.

The left column of Figure 1 shows two domain images taken with opposite helicity. The fact that the contrast is reversed between the two images indicates that it is indeed caused by FM domains. We can identify two types of domains separated by walls parallel to the image diagonal. The imbalance between areas covered by the different domains could be caused by residual fields or strain applied to the substrate during evaporation. If we compare the two images, we identify four different grey scales. However, the absolute intensity in each image can be misleading because the images are not normalized to the incoming intensity or to the pre-edge background. To extract quantitative information about XMCD intensity and the spin axes within each domain one needs to acquire local absorption spectra. This is achieved by taking images for subsequent photon energies and analyzing the image intensity in a certain area as it changes with energy afterwards. The resulting spectra are shown on the right side of figure 1. While the spectra in the small domains change drastically between the different helicities, the spectra in the bigger domains do not change very much. We calculate a variation in the L_3 peak intensity of 18% for the small domains which reaches 28% after correction for the degree of polarization (75%) and the angle of incidence 30°. This is the maximum value expected for bulk Fe, and we can conclude that the spin axis in these domains is in the surface plane and collinear with the light vector. The XMCD intensity of the other domains does not change upon reversal of the helicity, so their spin axis needs to be aligned perpendicular to the light vector. For this situation the cosine of the angle between the spin and the helicity does not change. In summary we observe two FM domains with their spin axes including an angle of 90°. If we take these experimental findings into account we can explain the preferred orientation of the walls parallel to the image diagonal. The magnetization vector rotates from one domain to the within the film plane forming a symmetric Néel wall, with the magnetization vector within the wall plane. This type of wall is typically observed for thin films when the film thickness is smaller than the wall width (about 15nm for Fe).

We conclude that Ge can be used as a substrate to grow FM films exhibiting 90° domains. Future studies will show if AFM films can be grown on top of the ferromagnetic film and how the domain size can be influenced.

References

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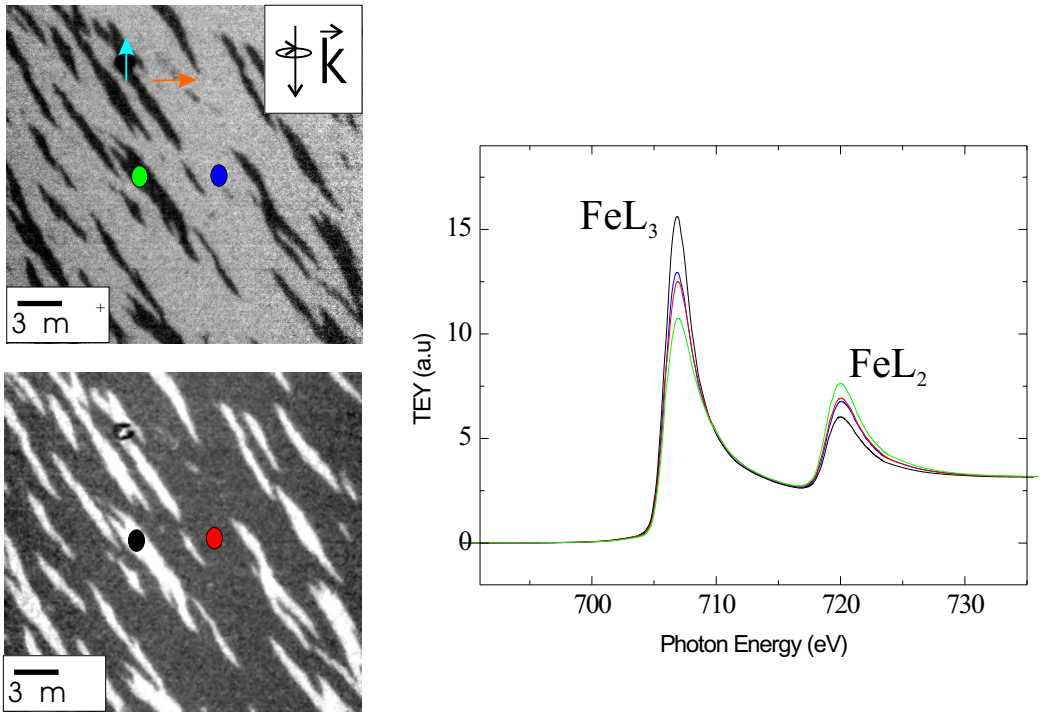

Figure 1: FM domain images taken with opposite helicity are shown on the left. The arrows in the upper image indicate the direction of the magnetization in each domain. The insets denote the dimensions and the helicity of the incoming light. Local x-ray absorption spectra were taken in each of the two domain types and with opposite helicity of the light ($\pm 75\%$ resulting into four spectra. The colored dots in the images correspond to the line color of the spectra. The spectra are shown on the right.

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